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THE PHOTO-COLORIMETRIC SPACE AS A MEDIUM FOR THE REPRESENTATION OF SPATIAL DATA

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SUMMARY

Spatial displays and instruments are usually used in the context of vehicle guidance, but it is hard to find applicable spatial formats in information retrieval and interaction systems. This paper discusses human interaction with spatial data structures and the applicability of the CIE color space to improve dialogue transparency. A proposal is made to use the color space to code spatially represented data. The semantic distances of the categories of dialogue structures or, more general, of database structures, are determined empirically. Subsequently the distances are transformed and depicted into the color space. The concept is demonstrated for a car diagnosis system, where the category "cooling system" could, e.g., be coded in blue, the category "ignition system" in red. Hereby a correspondence between color and semantic distances is achieved. Subcategories can be coded as luminance differences within the color space.

INTRODUCTION

The increasing dissemination of information technology as well as the expanding complexity of computer systems require user-friendly interaction techniques. One design goal of high relevance in the context of user friendliness is the transparency of system functions. In general, transparency is defined as a well-structured, consistent, and comprehensible appearance of the system for its users (Widdel and Kaster, 1986). One way to reach transparency consists of the design of a suitable menu structure. Especially for occasional and untrained users of computer systems a menu-based dialogue is of great advantage.

The designer of dialogues has to analyze the characteristics of the expected user group in order to adapt the dialogue interface to the mental model of the users. Knowledge of specific cognitive human behavior must guide the design of human-computer interaction in general, and of dialogue structures in particular.

A systematic or intuitive transfer of this basic knowledge of cognitive functions leads to iconic visualization of information in human-computer interaction. By presenting user commands and system information in iconic form, as pictures or three-dimensional presentations, better use is made of human visual capabilities.

GRAPHICAL DESIGN OF DIALOGUE STRUCTURE

The proposals made in this paper aim at further improving the graphical presentation of dialogue structures by considering three-dimensional concepts. This expands earlier work on dialogue design performed by Kaster and Widdel (1987). In comparing various dialogue designs, they used a conventional menu as given in figure 1a showing a menu with a set of five available choices. It includes title, menu options, selection codes, and the user query. Alternatively, they displayed the hierarchical organization of the dialogue structure as a picture. It encloses the total range of functions or menus offered in the dialogue. This picture is presented in figure 1b. The hypothesis underlying this experimental setup postulated that an interface design using a graphic conceptual model can facilitate the formation of an appropriate mental model of the interactive computer system (Bennett, Parasuraman, and Howard, 1984). The experiments of Kaster and Widdel confirmed this hypothesis and demonstrated that naive computer users can successfully run the dialogue with this interface.

The dialogue presented in figure 1 was used for experimental reasons and restricted to a relatively low complexity; real applications require much more complex dialogue structures. In terms of user-friendliness, research activities are focused on the breadth and depth as two relevant dimensions of dialogue complexity. Intensive and detailed discussions and investigations (MacGregor and Lee, 1987; Paap and Roske-Hofstrand, 1986) expand this problem area from the pure interaction field to the more general perspective of searching data bases.

High-resolution, direct-manipulation interfaces have been monochrome for a long time for technical reasons. As these restrictions are no longer valid, it is about time to consider reasonable applications of color. Distinct overviews of human factors knowledge about the use of color in visual displays is given by Davidoff (1987), Murch (1985), and van Nes (1986). In the context of this paper it will be of particular interest to show in which way color can be used to convey information about spatial structures instead of or in addition to 3-D graphics. For this purpose the colormetrics and psychometrics of color will be discussed in the next section.

COLORMETRICS AND PSYCHOMETRICS OF THE COLOR SPACE

Color can be defined by chromaticity and luminance; together they establish the photocolorimetric space (subsequently more simply called "color-space") as depicted in figure 2. The base plane described by the coordinates u' and v' defines the chromaticity of a color, while the third axis L gives the luminance (CIE, 1977). The luminance achievable with a standard TV monitor varies between 20 and 200 cd/m^2 depending on the color. Typical chromaticity coordinates are 0.42/0.54 for red, 0.12/0.57 for green, and 0.16/0.18 for blue. With these data the solid depicted in figure 2 roughly describes the color space available on commercial monitors. A color of particular chromaticity and luminance corresponds to a point in this color space (Kaster, Kraiss, and Küttelwesch, 1985).

The number of distinguishable points in the color space can be estimated from the number of just noticeable differences in chromaticity (jnd_C) and luminance (jnd_L).

The number of just noticeable luminance differences (jnd_L) is defined by the available luminance range and by the size of a threshold step. For the purposes of this paper we make use of a threshold contrast $C_L = 1.05$. This results in (Galves and Brun, 1975):

$$jnd_L = \log 1.05 = 0.021 \tag{1}$$

For comfortable discernibility, a value seven times larger usually is applied, i.e.:

$$jnd_L^* = 7 \times jnd_L = 0.15 \tag{2}$$

According to (1) a luminance range from 10 to 100 cd/m^2 can accommodate

$$(\log 100 - \log 10)/0.021 = 47.6 \text{ } jnd_L\text{'s}.$$

For the threshold chromaticity difference jnd_C Galves and Brun (1975) proposes a value of 0.00384 as the smallest color difference the eye can discern. Again, for practical purposes it is common practice to use a value seven times larger than the threshold for easy discernibility

$$jnd_C^* = 7 \times jnd_C = 0.027 \tag{3}$$

As an example we calculate with the numbers given above the distance between red and blue to be $(\Delta u'^2 + \Delta v'^2)^{1/2} = 0.354$. Hence, a total of $0.354/0.00384 = 92$ jnd_C's can be accommodated between these two colors. For simultaneous variations in luminance and chromaticity the number of discernible steps is determined by

$$jnd_{CL} = (jnd_C + jnd_L)^{1/2} \tag{4}$$

The photo-colorimetric space depicted in figure 2 offers ample opportunity for the composition of chromaticity/luminance trajectories. With respect to limited space only two representative examples are presented here. Tables 1 and 2 give their u',v',L-coordinates together with the number of jnd's contained in a particular trajectory (see also the corresponding figs. 3 and 4).

From previous experience in experiments with color-coded sensor data, it appears that observers can make a rather accurate estimate of distances in the color space (Kraiss and Küttelwesch, 1984). The number of absolutely discriminable states in the color space is, of course, much less than the number of jnd's. For chromaticity usually 6 to 9 and for luminance usually 6 values can be distinguished with sufficient reliability.

SEMANTICS AND COLOR SPACE

Any structure of a dialogue or database has a semantic system of categories underlying the organization. For example, a *car diagnosis system* contains the categories *electric system, suspension system, ignition system, cooling system, fuel system, and gear system* with appropriate subcategories on lower levels. The semantic distances of these categories can be determined empirically using multivariate methods of similarity scaling. The resulting similarity ratings establish a spatial structure, or semantic net, that may be used to build menu structures. Roske-Hofstrand and

Paap (1986) used this procedure to define menu organizations matched to the semantic net of experts for a cockpit information system.

Semantic distances can be depicted as chromaticity differences in the color space (fig. 5). In our example the categories *ignition* (C) and *cooling* (D) are separated by a long semantic distance which finds its equivalent in the long distance from red to blue. The categories *electric* (A) and *gear* (F), having a shorter semantic distance, are assigned to the colors green and cyan.

In selecting colors for menu options or categories, the psychology of color perception must be taken into account. Besides the correspondence of distances of both spaces, the problem of association between a category and a color arises, i.e., should category D be colored blue and category C red or vice versa. This problem can be solved empirically; sometimes appointments are predefined by tradition. While the association of blue with a cooling system and of red with an ignition system is evident, this is not the case for yellow (suspension system), green (electric system), cyan (gear system), and violet (fuel system).

Luminance as the third dimension of the color space may be used for coding the lower hierarchical levels of a menu structure or database (fig. 5) while retaining the chromaticity of the top-level category. Each category coded by a specific chromaticity is varying luminance with corresponding lower levels. In figure 5 the *cooling system* (D1) on the highest level may have a luminance of 24 cd/m^2. On the second level the *cooling system* could have, among others, the subcategories *water cooling* and *air cooling* (D2n). They will be assigned the same chromaticity coordinates, but on the second luminance level of 15 cd/m^2. On the third level a subcategory of water cooling could be water supply (D3nn) with a possible luminance of 5 cd/m^2.

Another possible application of color for the orientation in a multidimensional data space is proposed by Korfhage (1986). He describes a browser concept for navigating through a database by visual support. Browsing is defined as a dynamic search through an information resource, with no specific goal initially in mind. He models a set of documents as an n-dimensional space and simulates browsing by a loosely directed traversal of this space. Making use of the Doppler effect, documents far ahead of the actual search position were color-coded with blue; those far behind were color-coded with red. The document nearest to the user's plane is represented in yellow; transition color to blue is green and to red is orange.

CONCLUSIONS

A concept for the use of color to convey spatial information at the user interface was discussed. It was suggested that the color space can be used to represent spatially distributed or hierarchically organized data. This implies that an operator can form a corresponding mental color space model that enables him to associate chromaticity/luminance distances to geometric distances. Earlier experiments with color-coded sensor data suggest that this is possible. In an example a possible application of this concept to a car diagnosis database was described.

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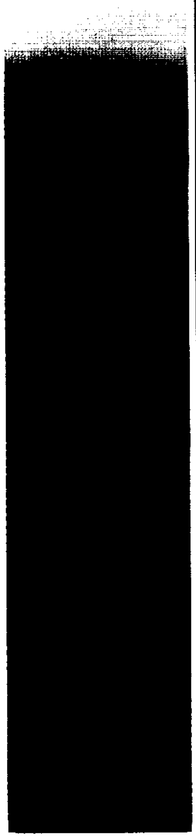
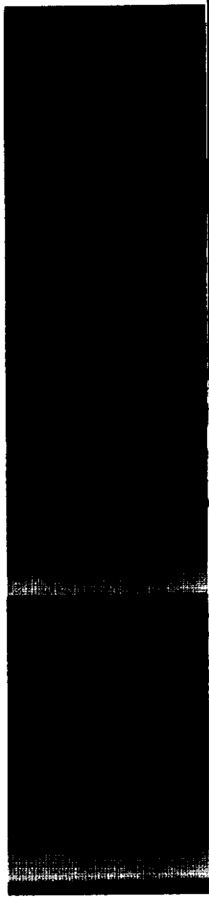
Table 1.– Chromaticity/luminance trajectory covering 249 jnd's. Presented are color scale, color space coordinates, and jnd's.



Reference	jnd's $_{CL}$	u	v	L cd/m^2
1		0,19	0,31	1
	48			
2		0,16	0,12	2
	41			
3		0,28	0,22	5
	51			
4		0,42	0,36	12
	59			
5		0,19	0,37	28
	22			
6		0,12	0,38	64
	28			
7		0,19	0,31	150

$\Sigma = 249$

Table 2.– Luminance scales for 6 chromaticities applicable to menu design. Presented are color scale, color space coordinates, and jnd's.



Reference	jnd's$_{CL}$	u	v	L cd / m^2
1				1
	67	0,16	0,12	
2				27
3				6
	65	0,13	0,30	
4				150
5				6
	65	0,12	0,38	
6				150
7				6
	65	0,19	0,37	
8				150
9				2
	62	0,42	0,36	
10				42
11				3
	67	0,28	0,22	
12				80

$\Sigma = 391$

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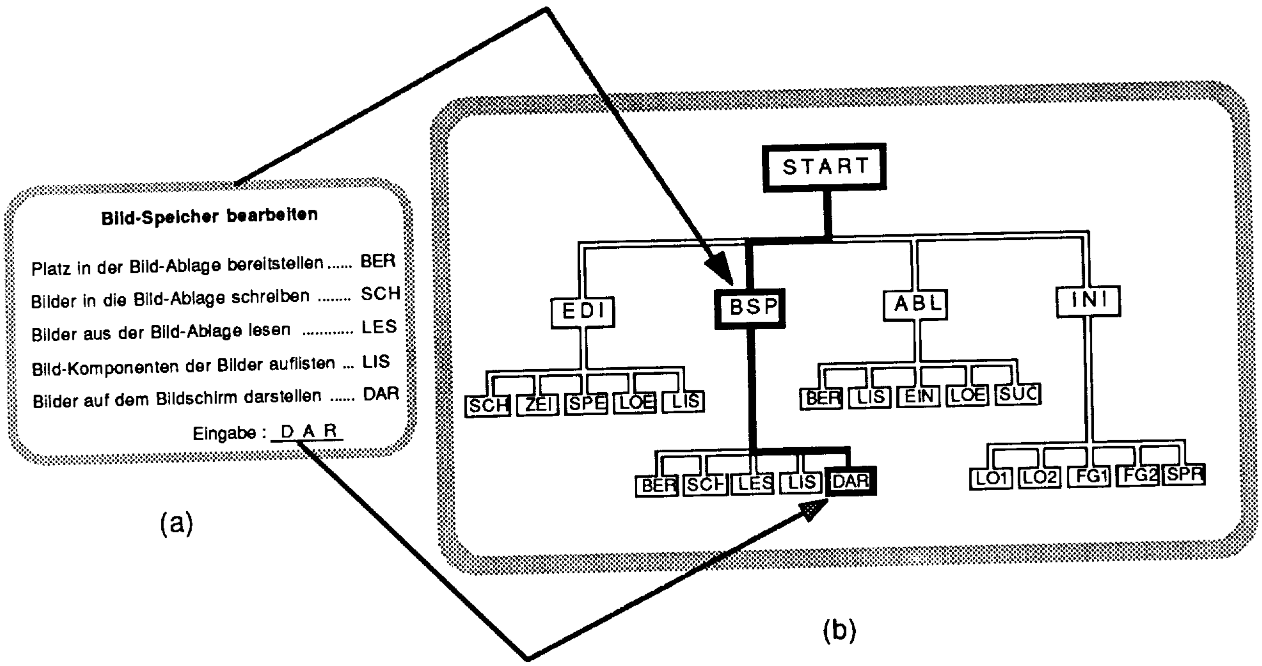

Figure 1.– Textual menu (a) and corresponding picture of the entire dialogue structure (b) (Widdel and Kaster, 1986).

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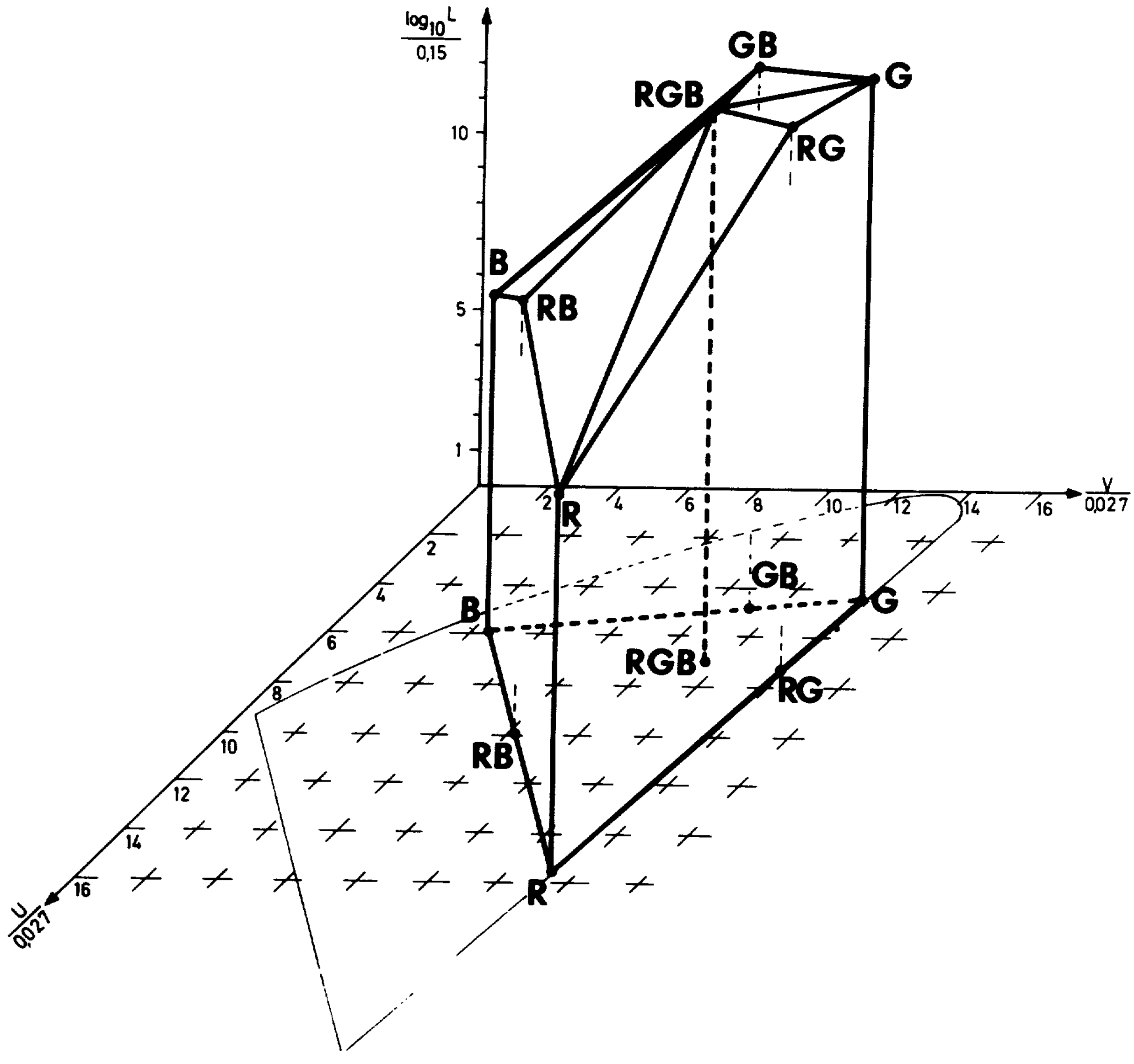

Figure 2.– The photo-colorimetric space with metrics of Galves and Brun (1975). The axes are scaled to just noticeable differences (jnd's).

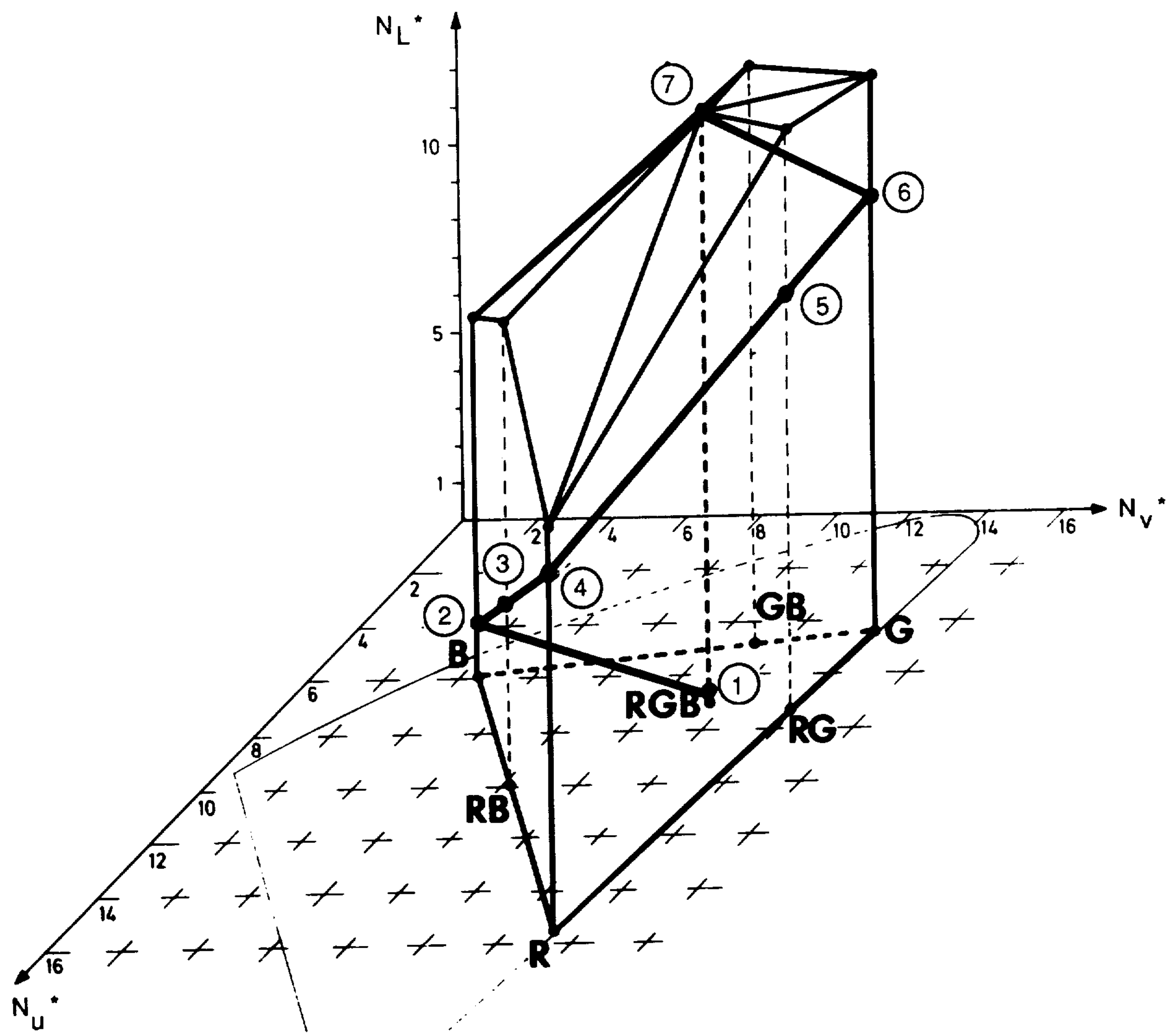

Figure 3.– Color space trajectory corresponding to the values given in table 1.

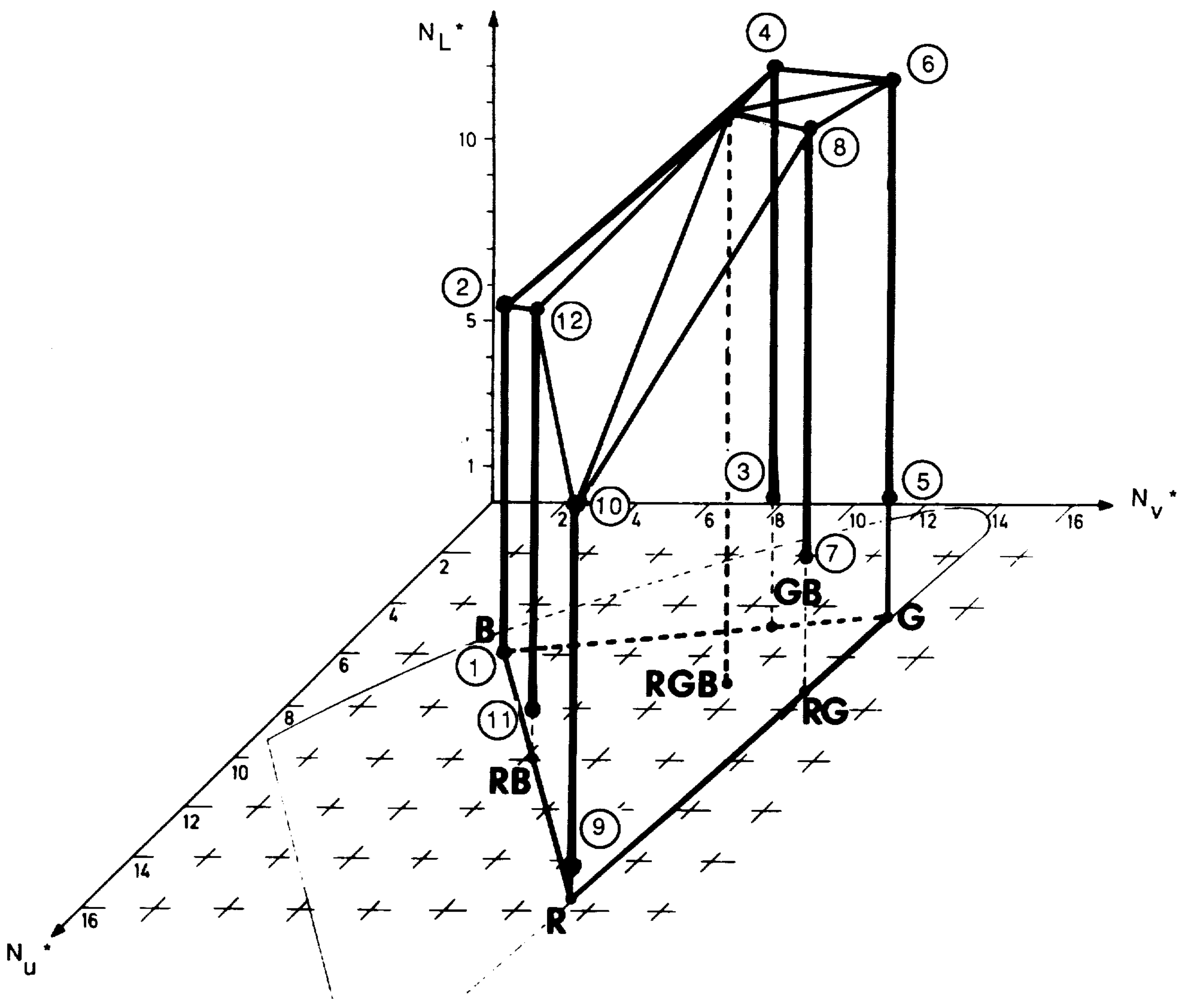

Figure 4.– Color space trajectory corresponding to the values given in table 2.

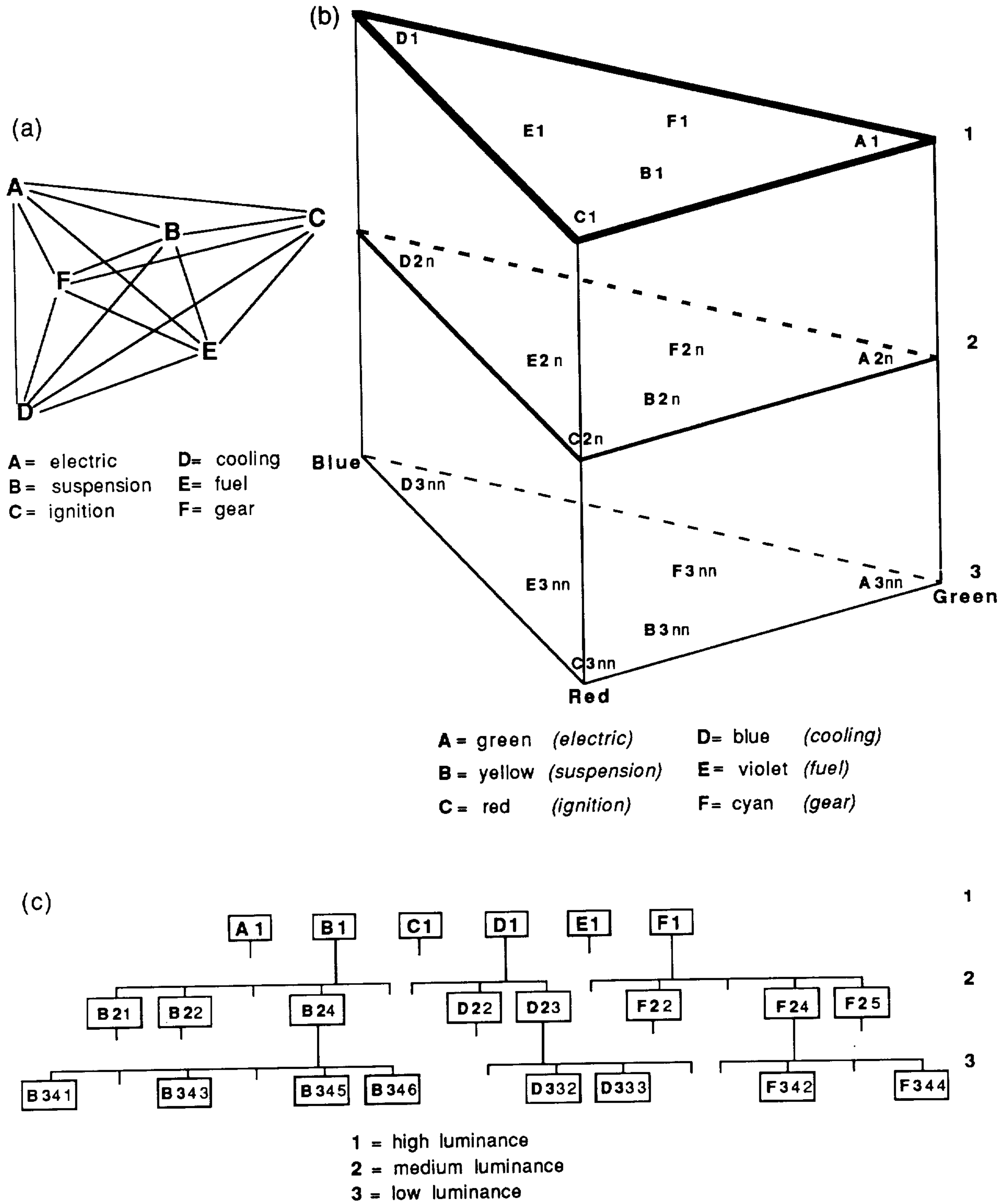

Figure 5.– (a) Fictitious net of semantic distances for categories in a car diagnosis system.
(b) The semantic net from (a) mapped onto the chromaticity plane. Three luminance levels are used to accommodate hierarchy subitems (see fig. 2). (c) Two-dimensional dialogue structure with additional chromaticity/luminance assignments to visualize semantic distances and hierarchy levels.